A REPORT ON THE SUCCESSFUL DEVELOPMENT OF UNDERGROUND COAL GASIFICATION AT HANNA, WYOMING

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INTRODUCTION

Previous authors have reported the results of several field tests of underground coal gasification (1). Prominent among these are the Russian work (1, 2) (which has included commercial utilization of UCG), the British tests (3), and early U.S. experiments (4-7). In 1973 the Bureau of Mines initiated the first of a series of field experiments near Hanna, Wyoming. This first test was designated Hanna I and has been previously detailed (8-11). The first Hanna experiment (Hanna I) was conducted from March 1973 through March 1974. Approximately 4000 tons of coal were utilized. During six months of optimum operation 1.6 MM scfd of 126 Btu/scf gas were produced.

Based upon the encouraging results of Hanna I, a second experiment, designated Hanna II, was initiated in 1975. This experiment was divided into three parts, called Phases I, II, and III. Phase I has already been reported (12) and will only be referred to as a basis of comparison. Phase I was conducted from June through August 1975. It yielded an average production of 2.7 MM scfd of 152 Btu/scf gas during 38 days of gasification between two wells on a 52.5 feet spacing. Approximately 1260 tons were utilized during the experiment. The results of Phases II and III are the subject of this report.

Description of the Process

The UCG process being tested by the Laramie Energy Research Center (LERC) is known as the Linked Vertical Well (LVW) technique. It involves two major steps: preparation of the coal seam followed by gasification as depicted in Figure 1. The preferred preparatory step is reverse combustion linking. The steps involved in reverse combustion linking are shown in Figure 1 A, B, and C. Wells are drilled and completed to the coal seam. A downhole electric heater is positioned in one well to ignite the coal. Air at a pressure slightly less than lithostatic pressure is injected at the ignition well to sustain a combustion zone. Then air injection is switched to an adjacent well. The injected air percolates through the coal seam to the ignition well and the combustion zone proceeds from the ignition well to the injection well, i.e., toward the source of oxygen. Because of this countercurrent movement of the injected air and the combustion zone, the process is, at this point, called reverse combustion. As this combustion zone proceeds to the injection well, a localized, highly permeable pathway of carbonized coal is left behind. When the combustion zone reaches the injection well, the system is ready for high volume, low pressure air injection which allows efficient gasification.

This preparatory step is extremely important because its location within the seam and its successful completion determine the future course of the gasification period. In addition, it is essential because coal in its natural unprepared state has insufficient permeability to enable air injection rates necessary for efficient coal gasification.

Figure 1 D, E, and F shows schematically the gasification step. Upon initiation of high volume, low pressure air injection, the gasification zone expands around the injection well until it encompasses the full seam thickness. The gasification zone then proceeds back toward the ignition well. Thus this step is a forward combustion process, i.e., reaction zone movement and gas flow in the same direction. In this manner the full seam thickness is gasified between two adjacent wells with high thermal efficiency.

Description of Hanna II

Phase I of Hanna II has been described in a previous paper (12). Phases II and III were conducted using the well pattern shown in Figure 2. The instrumentation wells were drilled and instrumented by Sandia Laboratories of Albuquerque, New Mexico, under ERDA funding (13).

The seam being utilized is the Hanna #1, a 30-feet thick subbituminous coal seam at a depth of approximately 275 feet at the Hanna II site. Wells 5, 6, 7, and 8 were completed 10 feet through the coal seam and perforated over the bottom 6 feet of the coal seam.

The original plan for conducting Hanna II, Phases II and III consisted of the following steps:

Phase II

1. Reverse combustion link Wells 7 and 8.
2. Reverse combustion link Wells 5 and 6.
3. Gasify from Well 6 to Well 5.

Phase III

1. Reverse combustion link from the 5-6 line to the 7-8 line.
2. Gasify in a line drive from the 7-8 line back toward the 5-6 line.

The main advantage of operating such a line drive system would have been improved areal sweep efficiency. Success of the technique was dependent upon the ability to form the broad reverse combustion link from the 5-6 line to the 7-8 line. This broad front link was not achieved and Phase III was modified to another two-well gasification system with gasification proceeding from Well 8 to Well 7. Phase II was completed as planned.

RESULTS OF HANNA II

Phase II

Reverse combustion linkage of Wells 7 and 8 was conducted during December 1975. Linkage of Wells 5 and 6 was completed in April and May 1976. No instrumentation was available along the 7-8 line to determine the location of the link, but as seen in Figure 2, the 8 wells between Wells 5 and 6 gave an accurate picture of the linkage path. Figure 3 shows the path of the link from Well 5 to Well 6 based on thermal data gathered during the linkage process.

Much more important is the location of the link within the coal seam relative to the bottom of the seam. The most advantageous position is within the bottom third of the seam. As the link proceeded from Well 5 to 6, the initial temperature rise observed at thermocouples in Wells D, O, G, E, and B always occurred at levels 0 or 5 feet above the bottom of the seam. Thus, placement of the link low in the seam was extremely successful. Positioning the link low in the seam allowed the gasification front to undercut the coal as it moved from Well 6 back to Well 5 after completion of the link. This resulted in fresh coal falling into the reaction zone yielding high resource utilization efficiency and producing a packed bed system.

The link was completed on May 4, 1976. Gasification from Well 6 to Well 5 was conducted from May 5 through May 30. Injection rates used were 1700, 2500, and 3500 scfm, respectively, in a programmed fashion as shown in Figure 4. Production rates, product gas gross heating value, and gas composition for the five major components are shown in Figures 4-6. As can be seen the step function increases in air injection rate had no effect on gas composition or gross heating value. Until the last eight days when the gasification zone approached Well 5, the heating value was extremely constant.

The total tonnage of coal utilized during both the linkage and gasification of the 5-6 system was 2520 tons. This value is based on a carbon balance using a weighted average composition determined from a core taken at the Hanna II site (14). This compares to 1260 tons utilized during gasification between two wells on a 52.5 feet spacing during Phase I. The improved utilization during Phase II is postulated to result from the higher injection rates, the positioning of the link at the bottom of the coal seam, and from holding 30 to 50 psig back-pressure on the production side. The estimated gasified area based on thermal data from the instrumentation wells and on modeling efforts conducted at LERC (15, 16) is shown in Figure 7. Thermal data indicates that at the midpoint of the 5-6 line the gasification zone was almost as wide as the 5-6 spacing.

Phase III

As previously stated, Phase III was modified from the proposed line drive system to another two-well experiment with gasification proceeding from Well 8 to Well 7. Again three pre-planned injection rates were used. These rates were 2500, 3500, and 4500 scfm, respectively. In addition, backpressuring the system was conducted to determine the effects of reservoir pressure changes on the gas composition.

Figures 8-11 show the injection and production rates, injection and production pressure, product gas gross heating value, and product gas composition for the five major components. Significant differences are seen in the heating value and composition when compared to data from the 5-6 system. The heating value dropped off much more rapidly during the lifetime of the 7-8 system.

The explanation for this difference is shown in Figures 12 and 13. Figure 12 shows the gross heating value, cold gas thermal efficiency, and ratio of water produced to coal utilized during the 5-6 gasification period. As can be seen, the heating value and cold gas efficiency were stable until Julian Day 142 (May 21, 1976) followed by a gradual decline.

In contrast, Figure 13 shows the same variables for the 7-8 gasification period. The heating value and cold gas efficiency show a steady decline from the beginning of the 7-8 gasification period with the most dramatic drop occurring around Julian Day 196 (July 14, 1976). That drop coincided with a planned decrease from 80 to 30 psig in the backpressure held on the system. The ratio of water produced to coal utilized increased sharply at that time. Compared to the 5-6 period, this ratio was approximately twice as high during the early stages of the 7-8 burn and six times as high after relieving the backpressure on Julian Day 196. This dramatic increase in water would be expected because groundwater influx should increase as the surface area of the cavity in the seam increases. In addition, decreasing the reservoir pressure further increased the water influx rate.

Increasing the air injection rate toward the end of the 5-6 burn would have stabilized the product gas heating value and cold gas efficiency since excess water does not appear to have been the cause of the decline in those two values. Also, an increased injection rate and higher backpressure during the last 20 days of the 7-8 burn would have improved the results of the 7-8 burn, but maximum air compression capacity had already been achieved.

The unique character of Phase III was the excellent resource utilization. The tonnage of coal utilized during Phase III was 4200 tons (Figure 14).

Overall, Hanna II is considered extremely successful even though the line drive process was unsuccessful. The total tonnage of coal utilized was 6690 tons, of which 680 tons were utilized during the unsuccessful line drive attempt. This is compared to the available 4600 tons contained within the 60 by 60 feet square of the 5, 6, 7, 8 well pattern. Obviously, coal was utilized outside that arbitrary boundary but exceeding this artificial total by such a margin indicates high resource utilization efficiency. Determination of the actual efficiency awaits coring and seismic surveys of the gasified area to finalize the true boundaries of the gasification zone, but there can be little doubt that UCG can achieve high resource utilization efficiencies under controlled conditions.

Energy Balance Calculations

Three different calculations have been previously reported (17). The first, defined as the energy return ratio, is simply the ratio of total usable energy produced from the process to total energy consumed in operating the process. This value must, of course, be somewhat greater than one for the process to be worthy of commercialization.

The second, defined as overall process efficiency, is the ratio of total usable energy produced from the process to total energy input to the process, i.e., the total energy consumed in operating the process plus the latent energy available in the amount of coal utilized. This value can, of course, never exceed one.

The third, defined as thermal efficiency, is the ratio of total usable energy from the process to total energy available in the amount of coal utilized. Again, this value can never exceed one.

The total energy produced from the process is the sum of five individual terms. These are the heat of combustion of the dry product gas, the heat of combustion of the liquid hydrocarbon byproducts, the sensible heat of the dry product gas, the latent and sensible heat of water vapor contained in the wet product gas, and the heat loss to ash and strata surrounding the coal seam.

For the purposes of this paper, the total usable energy produced from the process is defined as the sum of the heats of combustion of the dry product gas and of the liquid byproducts. No credit is taken for either the latent or sensible heats. The results of these calculations are shown in Table I.

Table I. Energy Balance Results for Hanna II

	Phase		
	I	II	III
Energy Return Ratio	5.3	4.5	4.5
Overall Process Efficiency (%)	71.5	74.3	65.3
Thermal Efficiency (%)	82.7	89.0	76.3

Accomplishments of Hanna II

Hanna II yielded several outstanding accomplishments in the field of UCG using air injection. These were the following:

1. Production of the highest gross heating value product gas over the longest duration ever reported.

2. Operation at the highest thermal efficiencies ever reported.

3. Highest production rate from any UCG test in the Free World.

4. High overall sweep efficiency for parallel two-well patterns.

5. The most thoroughly instrumented UCG test ever conducted.

CONCLUSIONS

Based on the results of Hanna II, a large number of predicted problem areas attributed to in situ coal gasification technology do not appear to be of significance. Stable operation at high production rates with relatively constant gas quality and composition have been achieved. Overall process and thermal efficiencies were high and resource recovery was excellent. No detectable gas leakage occurred based on nitrogen and argon balances. No shutdown due to equipment or process failure was encountered. Process control based on adjustment of air injection rate to maintain the optimum air/water ratio appears feasible. Future tests planned at Hanna will concentrate on further demonstration of these conclusions and will address the major unknowns still associated with the in situ coal gasification process, i.e., the effects of subsidence and the determination of optimum and maximum well spacings.

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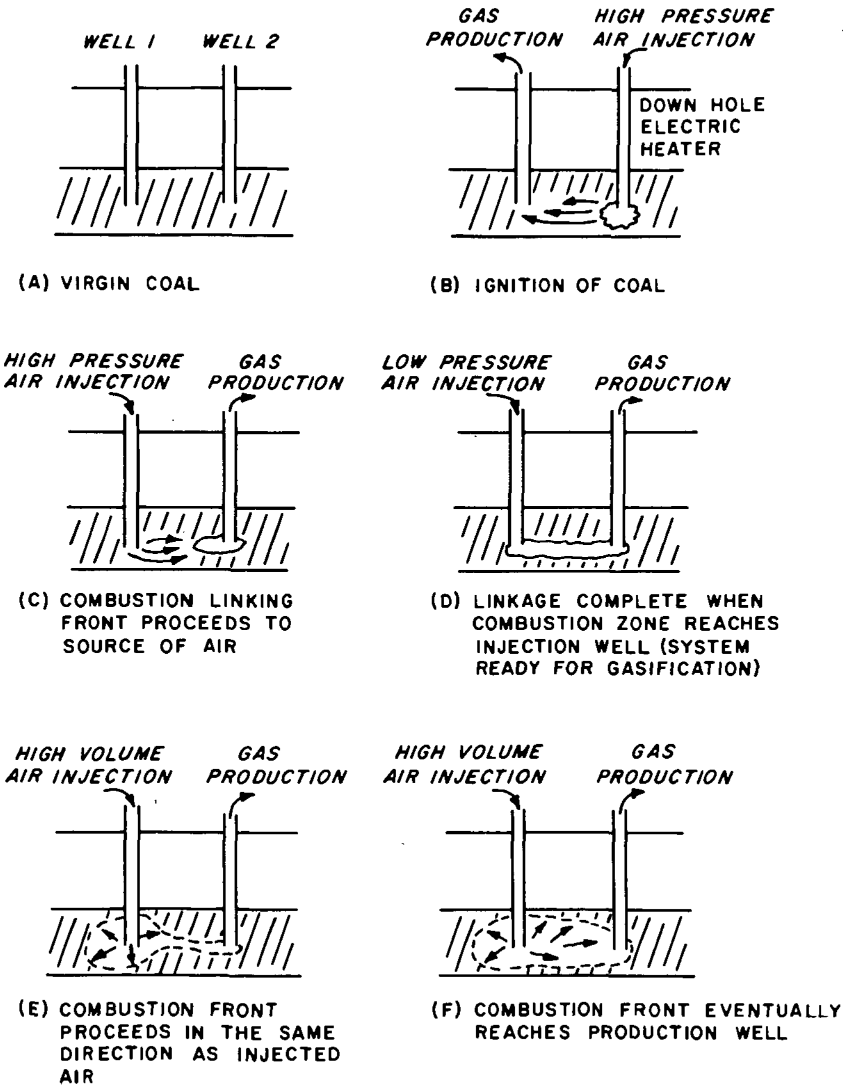

Figure 1 - Schematic of the LVW UCG Process

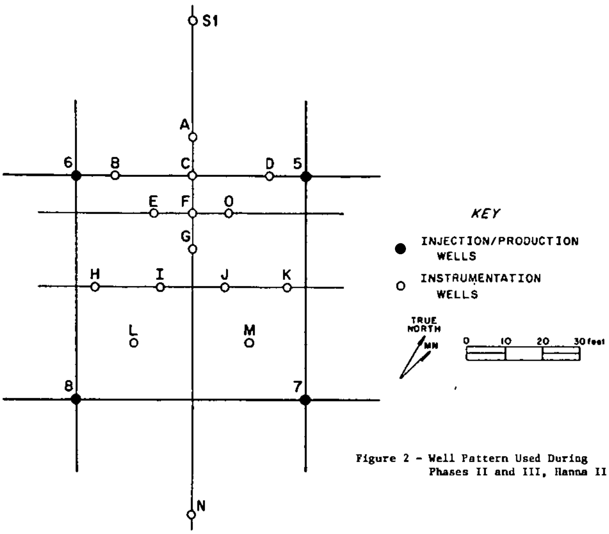

Figure 2 - Well Pattern Used During Phases II and III, Hanna II

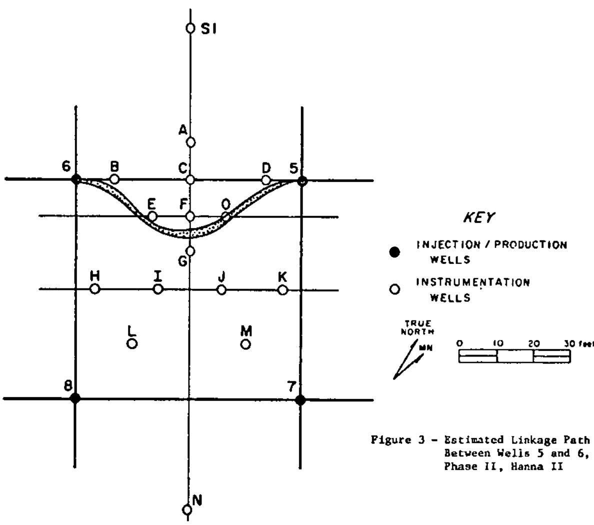

Figure 3 - Estimated Linkage Path Between Wells 5 and 6, Phase II, Hanna II

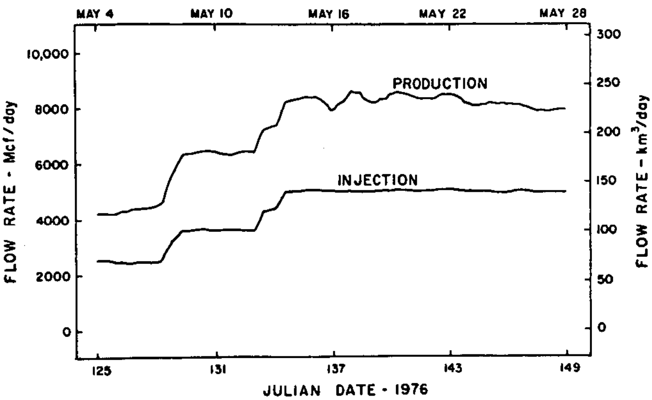

Figure 4 – Injection and Production Rates,
Phase II, Hanna II

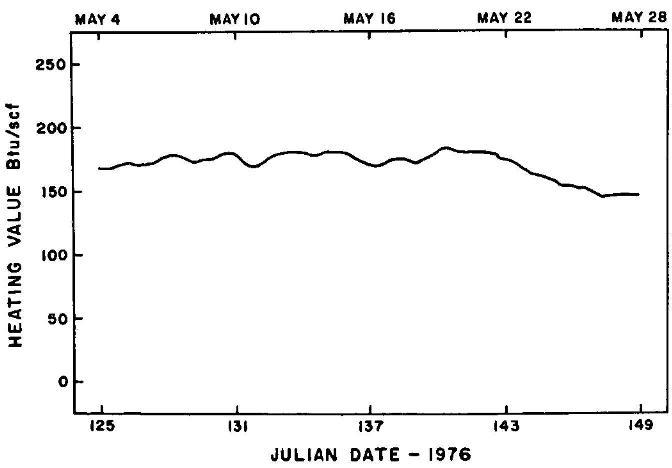

Figure 5 – Product Gas Gross
Heating Value,
Phase II, Hanna II

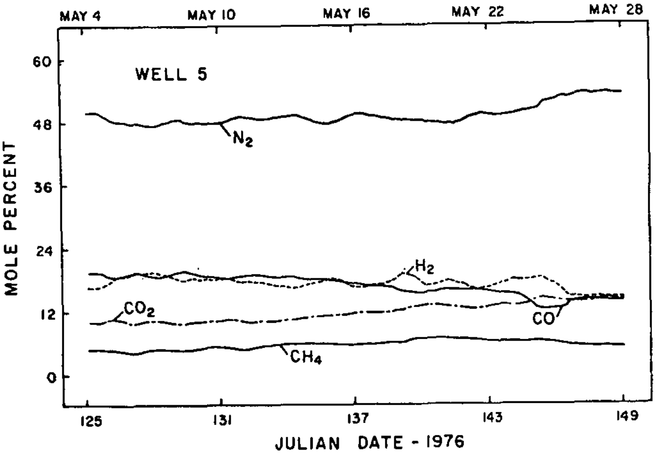

Figure 6 - Product Gas Composition, Phase II, Hanna II

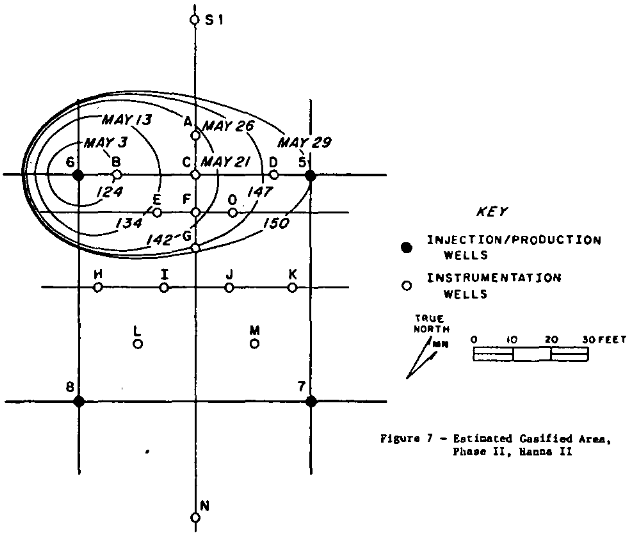

Figure 7 - Estimated Gasified Area, Phase II, Hanna II

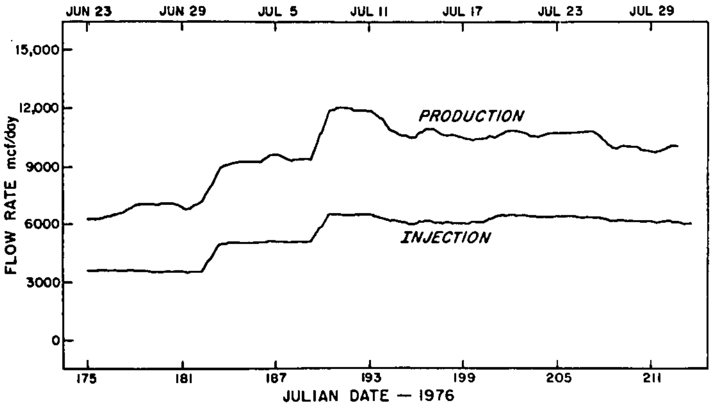

Figure 8 - Injection and Production Rates, Phase III, Hanna II

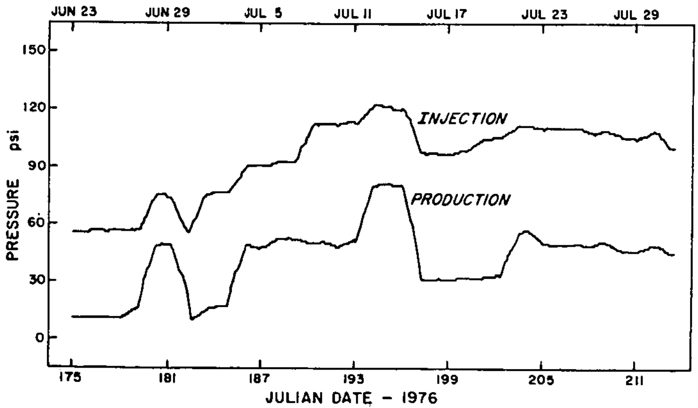

Figure 9 - Injection and Production Pressures, Phase III, Hanna II

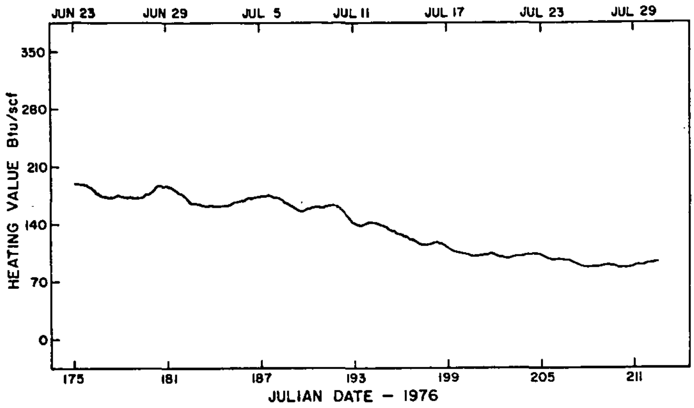

Figure 10 - Product Gas Gross Heating Value, Phase III, Hanna II

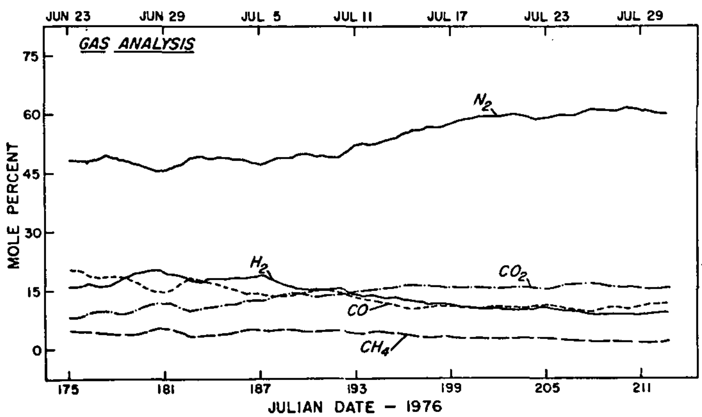

Figure 11 - Product Gas Composition, Phase III, Hanna II

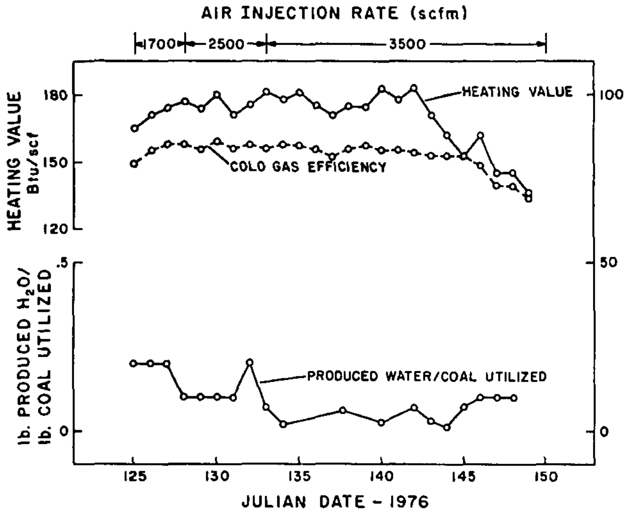

Figure 12 - Effects of Water Influx on Phase II, Hanna II, Results

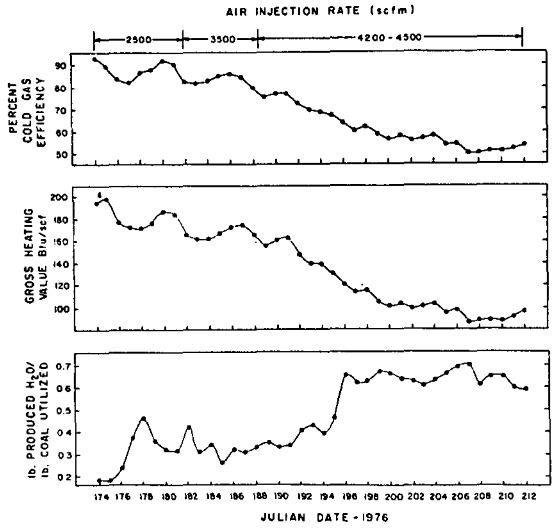

Figure 13 - Effects of Water Influx on Phase III, Hanna II, Results

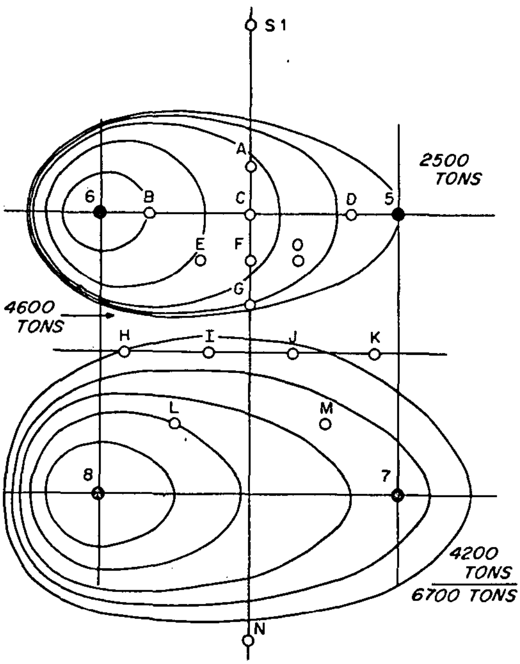

Figure 14 - Estimated Gasified Area,
Phases II and III,
Hanna II